EXHIBIT 5

Introduction to Colloid and Surface Chemistry

Third Edition

DUNCAN J. SHAW, BSc, PhD
Principal Lecturer in Physical Chemistry,
Department of Chemistry and Biochemistry,
Liverpool Polytechnic

BUTTERWORTHS
London – Boston
Sydney – Wellington – Durban – Toronto

BEST AVAILABLE COPY

(Shaw).

Ion exchange

Ion exchange involves an electric double layer situation in which two kinds of counter-ions are present, and can be represented by the equation

$$RA + B = RB + A$$

where R is a charged porous solid. Counter-ions A and B compete for position in the electric double layer around R, and, in this respect, concentration and charge number are of primary importance. R may be a cation exchanger (fixed negatively charged groups, such as $-SO_3^-$ or $-COO^-$) or an anion exchanger (fixed positively charged groups, such as $-NH_3^+$). A range of highly porous synthetic cation and anion exchange resins are available commercially. The porosity of the resin facilitates fairly rapid ion exchange.

The most important applications of ion exchange are the softening of water and the 'deionisation' of water.

In the first of these processes, hard water is passed through a column of a cation exchange resin usually saturated with sodium counter-ions. The doubly charged (and, therefore, more strongly adsorbed) calcium ions in the water exchange with the singly charged sodium ions in the resin, thus softening the water. Regeneration of the resin is effected by passing a strong solution of sodium chloride through the column.

The 'deionisation' of water involves both anion and cation exchange. A cation exchange resin saturated with hydrogen ions and an anion exchange resin saturated with hydroxyl ions are used, often in the form of a mixed ion exchange resin. These hydrogen and hydroxyl ions exchange with the cations and anions in the water sample and combine to form water.

Ion exchange has many preparative and analytical uses; for example, the separation of the rare earths is usually achieved by cation exchange followed by elution of their complexes with citric acid.

ELECTROKINETIC PHENOMENA[107]

Electrokinetic is the general description applied to four phenomena which arise when attempts are made to shear off the mobile part of the electric double layer from a charged surface.

If an electric field is applied tangentially along a charged surface, a force is exerted on both parts of the electric double layer. The charged surface (plus attached material) tends to move in the appropriate direction, while the ions in the mobile part of the double layer show a net migration in the opposite direction, carrying solvent along with them, thus causing its flow. Conversely, an electric field is created if the charged surface and the diffuse part of the double layer are made to move relative to each other.

The four electrokinetic phenomena are as follows:

(1) *Electrophoresis* – the movement of a charged surface plus attached material (i.e. dissolved or suspended material) relative to stationary liquid by an applied electric field.
(2) *Electro-osmosis* – the movement of liquid relative to a stationary charged surface (e.g. a capillary or porous plug) by an applied electric field (i.e. the complement of electrophoresis). The pressure necessary to counterbalance electro-osmotic flow is termed the *electro-osmotic pressure*.
(3) *Streaming potential* – the electric field which is created when liquid is made to flow along a stationary charged surface (i.e. the opposite of electro-osmosis).
(4) *Sedimentation potential* – the electric field which is created when charged particles move relative to stationary liquid (i.e. the opposite of electrophoresis).

Electrophoresis has the greatest practical applicability of these electrokinetic phenomena and has been studied extensively in its various forms, whereas electro-osmosis and streaming potential have been studied to a moderate extent and sedimentation potential rarely, owing to experimental difficulties.

Electrophoresis[108]

A number of techniques have been developed for studying the migration of colloidal material in an electric field.

Particle (microscope) electrophoresis

If the material under investigation is in the form of a reasonably stable suspension or emulsion containing microscopically visible particles or